SOME EFFECTS OF INSECTICIDES ON TERRESTRIAL BIRDLIFE IN THE MIDDLE WEST

A Contribution from the Wilson Ornithological Society Conservation Committee

The object of this paper is to present an ecological review of the presently known effects of insecticides upon bird populations in terrestrial habitats in Wisconsin and (to a lesser extent) in the neighboring states of Michigan and Illinois. The omission of aquatic phenomena in this report has one serious drawback that the reader should recognize at the start: Very little attention in this paper is given to destruction of aquatic insects and fish-food organisms in routine forest spraying (Hoffmann and Merkel, 1948; Hoffmann, Townes, Swift, and Sailer, 1949; Hoffmann and Drooz, 1953) or to the heavy losses of invertebrate animals when marshland has been sprayed for mosquito control (Springer and Webster, 1949, 1951) or to the delayed effects on fish (Surber, 1948; Herald, 1949). These phenomena presumably have an effect on bird populations, although this effect is seldom measured; but they involve aquatic birdlife for the most part, they have seldom been studied in the Middle West, and they are outside the scope of the present review.

I am much indebted to a great many patient colleagues in other institutions, as well as at the University of Wisconsin, who critically read an early draft of the present paper. Without the availability of Rudd and Genelly's (1956) fine monograph on the relationship of pesticides to wildlife, the writing of this paper would have been doubly difficult. The present review is a slightly condensed version of a multilithed report which the State of Wisconsin distributed in limited numbers early in 1961 as part of a study carried out by the Governor's Special Committee on Chemicals and Health Hazards.

ECOLOGICAL CHARGES OF WILDLIFE CONSERVATIONISTS

FEARS REGARDING DIRECT MORTALITY

Many conservationists believe that the direct mortality sustained by wildlife is steadily increasing as the gross tonnage of insecticides sold each year continues to mount. Allied to this widespread feeling is awareness that insects develop resistance to certain insecticides and that society is faced with the prospect of more and more poisons of higher and higher toxicity. Statistics annually compiled by the Commodity Stabilization Service (Shepard, 1956; Shepard, Mahan, and Graham, 1959, 1960) to some extent bear this out. From 1952–53 to 1958–59, domestic "disappearance" of DDT (domestic use plus some export shipments by formulators) increased only 12 per cent (from 62.5 to 78.7 million lb.). At the same time, six much more toxic chlorinated hydrocarbons increased 115 per cent (from 34.1 to 73.3 million lb.). Wildlife hazard is, however, much more closely related to manner of use than to volume. Thus, applications of aldrin or heptachlor (at 1 lb./acre, for soil-insect pests) involve almost one-half of all the crop acres treated with insecticides in Illinois and Wisconsin (Mills, 1956; Dicke, 1960). Here the chemicals must be disked into the soil at once, since delays of even 1 hour can affect the results (Mills, 1955). It is unlikely that birdlife is appreciably affected by this method of application. Occasional delays in coverage of the insecticide are reported, however, in Illinois (Bigger and Blanchard, 1959); and, in the opinion of A. W. Schorger (pers. comm.), the three birds most likely to be exposed to the chemical in the Middle West are Herring Gulls (*Larus argentatus*), Ring-billed Gulls (*L. delawarensis*), and Pectoral Sandpipers (*Erolia* *melanotos*). We have no evidence, however, that any unusual mortality among these species is taking place; and it is my judgment that the wildlife hazard involved in this particular use of insecticides must be very small. The difficulties of generalizing from the toxicity of an insecticide, from the total volume used, and from application rates are always compounded by the place of application—since some landscapes have high densities of birdlife (forest edges, wetlands, and well-landscaped suburbs) while others support almost no birds at the time insecticides are applied to them (plowed cornfields, potato fields, and the like).

It seems wisest, therefore, to avoid sweeping generalizations about the over-all effect of pesticides upon wildlife until one can evaluate particular programs of insect control where the individual variables are better understood and where less extrapolation from known facts is necessary. Even here, however, it is rather difficult to get good data on the magnitude of everyday control programs; and—partly as a result—public attention has tended to focus on the spectacular emergency projects.

Forest-insect Control

Forest-insect control is of great interest to sportsmen, since the ungrazed 195 million acres of forested land today provide major opportunities for hunting and fishing in the United States. In 1957, the forested area subjected to aerial applications of insecticides in this country was 10.3 million acres (Shepard et al., 1959). As it is not necessary to protect every branch of every tree (as in Dutch elm disease operations), forest-insect control here is chiefly confined at the present time to single applications of DDT at 1 lb./acre. These do not seem to affect mammals (Stickel, 1946, 1951; Adams, Hanavan, Hosley, and Johnston, 1949); their direct effect on birdlife is negligible (Kozlik, 1946; Kendeigh, 1947; Adams et al., 1949); and at the present time, they are not known to damage the general arthropod fauna seriously, but in this latter connection many forest types having a variety of canopy densities still remain to be studied with a precise, statistically adequate method (Hoffmann et al., 1949; Hartenstein, 1960).

Barker (1958) found that June and July applications of 1.5 and 1.1 lb. of DDT per acre can be concentrated sufficiently by earthworms to kill Robins (*Turdus migratorius*) during the following spring. Although this study involved a nonforested area, there is, therefore, a possibility that the earthworm-feeding Woodcock (*Philohela minor*) may similarly be affected by forest spraying. In northern New Brunswick, where (as of 1959) applications of 0.5–1 lb. of DDT per acre have been annually repeated for as many as 5 years, Wright (1960) has found a marked reduction in the reproductive success of Woodcock. This finding represents the first field evidence of a phenomenon previously produced under laboratory conditions; the evidence is, however, circumstantial and should be followed up by chemical analyses of the northern birds that are involved. Pesticide usage in Canada differs from that carried out against forest-insect defoliators in the United States: (1) Applications of DDT in New Brunswick are now reduced to 0.5 lb./acre; and (2) 55.5 per cent of the sprayed area there has been treated twice, 28.3 per cent three times, and 2.5 per cent four times (Webb, 1959). As far as I can learn, these replications are very rare in the Middle West. In Wisconsin's forests, treatment in two successive years seems to have occurred only on a few small pine plantations during the past decade.

The European pine shoot moth is a local pest that has recently reached the Middle West and now occupies the Lower Peninsula of Michigan as well as southern and eastern Wisconsin (Benjamin, Smith, and Bachman, 1959). This species can be controlled only with very heavy applications of DDT—some of which go up to 10 lb./acre (Miller and Haynes, 1958). These treatments are carried out by Christmas-tree operators (chiefly in Michigan), and only local bird populations are probably affected. The insect does relatively little damage to white pines or to pine plantations over 15 ft. in height; and its further spread in the Middle West is restricted by its inability to overwinter at −18°F. (Benjamin et al., 1959). Although no evaluations of the wildlife effects of shoot moth spraying have been carried out, the wildlife-conservation problem here seems to be essentially a limited one.

Agricultural-insect Control

Agricultural-insect control has been only slightly studied by wildlife ecologists. There is, of course, a great deal of regional variation in the distribution of insect pests and a parallel variation in the use of insecticides. In 1955, farmers in Illinois used insecticides on 1,531,000 acres—mostly for corn borers and soil insects (Mills, 1956). In Wisconsin, the crop acreage in 1959 was about 295,000 (Dicke, 1960). On the whole, it has been very difficult for an ecologist to get these statistics for each state and to form some preliminary idea of the magnitude of the bird mortality that may or may not be taking place. Dicke's (1960) statistical data for Wisconsin are among the very best that lend themselves to an ecological review, and my preliminary estimates of the bird mortality taking place in that state in 1959 (Table 1) must be regarded as working hypotheses rather than conclusions based on rigorously established facts. These hypotheses really rest on comparative toxicological studies of laboratory animals (as summarized by Rudd and Genelly, 1956, and Negerbon, 1959) and on field studies of the effects of DDT on forest birdlife where experimental application rates have reached 3–5 lb./per acre (Hotchkiss and Pough, 1946; Robbins and Stewart, 1949; Mitchell, Blagbrough, and Van Etten, 1953).

It is virtually impossible at this time to make any estimate of the late-summer effects of agricultural insecticides on wildlife. In the fall and winter, when the cornfields of the Middle West are highly important feeding areas for both game species and for songbirds, insecticides do not appear to have any negative effects on these animals . . . and in their contribution to high yields, it can be said that insecticides have helped Midwestern farmers to tolerate the wastage in mechanically picked corn that is now so important to Canada Geese (*Branta canadensis*), Mallards (*Anas platyrhynchos*), and Ring-necked Pheasants (*Phasianus colchicus*) in this region.

In general, it seems to me quite possible that modern orchards have lost most of their birdlife. Unpublished summer-transect data from Illinois indicate that this may not be true in that state (Graber, pers. comm.). Most of the orchard-wildlife-loss reports elsewhere on the continent come from British Columbia, Washington, and California (Rudd and Genelly, 1956) where DDT and TEPP seem to be the insecticides most frequently involved when the observations were carried out. Songbird mortality from parathion is said to be frequent in citrus groves, but the extent of such loss is not known (Rudd and Genelly, 1956). No conclusive research has been carried out on such very important variables as the size of the orchard area that is sprayed and on the chronological aspects of spraying as they relate to the nesting cycles of both game and songbirds.

Among wildlife conservationists, there exists some fear that agricultural insecticides tend to increase toxicological hazards for migratory birds which—quite apart from their avoidance of cropland during the breeding season—are often found on farm fields during the migratory and wintering periods of their annual cycle. Only fragmentary data on the presence of insecticidal residues in the tissues of such birds are currently available to test this hypothesis in a critical and conclusive fashion. Pending the finality of such tests, I believe that three facts mitigate against the hypothesis being true in the Middle West: (1) The organic phosphates used during the plant-growing season have too short

TABLE 1
PRELIMINARY ESTIMATES OF THE EFFECT OF AGRICULTURAL AND FOREST INSECTICIDES ON WISCONSIN BIRDLIFE

Crop	Per cent Treated in Wis.[6]	No. of 1,000 Acres[1] Treated	Principal Insecticide Used on Crop[1]	Total Lb. per Acre[1,2]	Bird Populations[3]		Estimated Mortality to Birds Present[5]
					Nesting	Feeding[4]	
FIELD CROPS							
Forage	1.2	50	Malathion or parathion	0.25 or 0.5	Fair (48)	Good	None or slight?
Field corn	3.6	100	Aldrin or heptachlor[6]	1	V. low (3)	Good	None
Sweet corn	11.7	12	DDT	3.0(2)	None?	Good	–?–
Soybeans	1.0	1	DDT	1	Low?	–?–	None
Peas	7.0	6.5	Parathion	0.67(2)	Low	Low	Slight?
Small grains	0.7	20	Parathion or malathion	0.25 or 0.5	Low (10)	Low	None or slight?
Tobacco	33.0	4.6	Aldrin or heptachlor[6]	2	None	None	——
VEGETABLES							
Cabbage	95.6	5.5	Endrin	1(2)	None	Poor	——
			Parathion + toxaphene	1.5 + 4.5 (3)	None	Poor	——
Carrots	50.0	0.9	DDT	8(4)	None	None	——
Onions	75.0	2.1	Ethion[6]	1	None	None	——
Cucumbers	25.0	4	DDT	0.5–1 (1–2)	None	None	——
Potatoes	95.0	42.8	DDT + toxaphene[7]	6.8 + 9 (8–9)	None	None	——
FRUIT CROPS							
Apples	100	10	Dieldrin Lead arsenate DDT TDE	0.25 30(5) 10(5) 8(4)	High	High	98%
Cherries	100	10	DDT Malathion or parathion Methoxychlor Dieldrin	3 4.5 or 1.5(2) 3 0.25	High?	High	98%
Cranberries	100	4.5	Parathion	0.3(2)	Low	Low	None
Strawberries	100	1.5	Parathion or malathion Methoxychlor TDE	0.5 or 1.5 1 1	Low	High	Slight
PULP, TIMBER							
Forests[8]	1.0	20.4	DDT	1	Good (225)	Good	None
Planting	11.3	6[9]	Aldrin[6]	0.4[10]	Low	Low	None

[1] From Dicke (1960) except as noted below; treated acres represent 1959 data.
[2] The total number of treatments per growing season is given in parentheses.
[3] Subjectively estimated (with help from R. A. McCabe and A. W. Schorger, Univ. of Wis.) for pre-insecticide conditions. Some actual densities for SCS-planned farms in Ohio (Dambach and Good, 1940) are shown in parentheses as pairs per 100 acres.
[4] Excludes late summer, fall, and winter.
[5] Crudely estimated; based in part on summary by Rudd and Genelly (1956).
[6] Soil treatments to which birds are not generally exposed.
[7] The switchover to systemic phorate in 1961 (Dicke, 1960) should not change the mortality estimates. Total lb./acre calculated for nine applications.
[8] Four-year average (1956–59) calculated from Benjamin's (1960) compilation.
[9] State-wide estimate by S. W. Welsh, Wisconsin Conservation Dept. (pers. comm.).
[10] Estimated by R. W. Shenefelt, Dept. Entomology, Univ. of Wis. (pers. comm.).

TABLE 2

SUMMARY OF MAJOR USES OF INSECTICIDES IN RURAL WISCONSIN IN 1959[1]

Crop Treated	Acres Treated	Lbs. Insecticide Used	Lb./Acre	Est. Bird Loss
Field crops	194,000	168,000	0.87	None to slight
Vegetables	55,300	726,000	13.13	None
Fruit crops				
Apples, cherries	20,000	572,500	28.63	Very considerable
Others	6,000	5,900	0.98	None to slight
Forests	26,400	22,800	0.87	None
Totals and means	321,800	1,495,200	4.64	Over-all: slight

[1] Insecticide treatment for outbreaks of migratory insects is variable and cuts across all crops. In 1960 about 20,000 acres were treated for grasshopper control, about 44 per cent with malathion, and 38 per cent with aldrin (Dicke, 1960).

a residual life to be available to migrating birds in fall or winter; (2) the aldrin, dieldrin, or heptachlor used for soil insects is disked into the soil and hence is unavailable for direct ingestion by birds in this region; and (3) most of these field-foraging birds are hunting for seeds rather than for insects during the fall and winter.

The use of malathion and parathion on alfalfa takes place in July and does not involve the first cut of this forage crop. The year's second growth of alfalfa rarely is attractive to nesting birds (R. A. McCabe, pers. comm.). It does attract feeding birds from nearby fields. As far as I can determine from Rudd and Genelly's (1956) excellent review, applications of these organic phosphates at such low concentrations may well have only a slight effect on birdlife.

For Wisconsin, the serious bird mortality on crop and orchard land seems to be confined to about 20,000 acres—an area representing less than 0.06 per cent of the 35,011,200 acres in the state. Although almost 1.5 million lb. of insecticides are used in this state's agricultural and forestry operations (Table 2), the over-all direct effect on the state's birdlife seems to be slight.

Dutch-elm-disease Control

Dutch-elm-disease control has been rapidly expanded within the past decade as this disease moved into the Middle West where street elms are extensively planted in many residential areas on former prairies and farmlands. The disease was first identified in Cincinnati and Cleveland in 1930, in Detroit in 1950, in Chicago in 1954, in Wisconsin in 1956, and in Iowa in 1957. As a very preliminary guess, one might say that the threatened street elms in this region may number about 1.5 to 2 million trees. The dollar value of these is hard to assess and probably exceeds the net cost of removing a dead tree. Taken at $250 per tree, these street elms could well represent a resource totaling 375–500 million dollars. Whatever the true value of this resource really is, one may conclude that the problem facing state and municipal authorities is indeed an immense one that demands our most earnest thinking.

Variations in DED-control techniques can be arbitrarily classified into three types that are of particular interest to the ornithologist. Each importantly depends on sanitation (tree trimming, clean-up of elm wood piles, etc.). Each has its own (known or suspected) wildlife effects; and almost every possible gradation between the three has been used during the past decade.

Sanitation.—The first and apparently the oldest of these types involves sanitation alone. Some of the cities relying on this technique are quite large, like Buffalo (185 thousand public and private elms, with a disease loss averaging 0.4 per cent per year from 1953 through 1956 according to Matthysse, 1958). These cities—as far as I know—are all in the East. The tree trimming probably has at least a slight depressing effect on local bird populations, but this has never been measured. [The Chickadees (*Parus atricapillus*), woodpeckers (*Dendrocopos pubescens* and *D. villosus*), and Nuthatch (*Sitta carolinensis*) populations—which are most likely to be affected—could be in part restored by erection of artificial nest boxes.] This program was used in 1959–60 at Shorewood, Wisconsin; but no community in the Middle West seems to have relied on it exclusively from the start. In New York State, where the disease was discovered in 1930, Matthysse (1958) recommends that sanitation receive the main emphasis and that DDT be used for high-value, healthy elms. Such a system presumably has wildlife effects that will be somewhat intermediate between the sanitation type and the DDT programs described below.

DDT.—In the Middle West, control of DED is principally carried out with application rates of DDT that have been roughly estimated by George (1959) as running 5–10 lb./acre, but we in Wisconsin have calculated local treatments as high as 17.2 and 23.6 lb./acre (Hickey and Hunt, 1960*a*). There are four variables affecting these rates: the height of the tree, the number of elms per acre, the use of mist-blowers vs. hydraulic equipment, and the application technique of the machine operator. Elm losses in 12 Illinois communities using this technique were less than 1 per cent per year from 1956 through 1959 (Neely, Carter, and Compana, 1960). All the published reports of bird mortality associated with routine DED control during the past decade are restricted to Michigan, Illinois, and Wisconsin where this use of DDT is quite common and where it has tended to be introduced in full-scale programs of spraying.

In Michigan, at least 18 residential communities are now known to have sustained bird mortality as a result of these programs; breeding-bird mortalities on the order of 90 per cent or more have been recorded; and 94 species of birds are known or are suspected to have died from DDT poisoning (Mehner and Wallace, 1959; Wallace, 1960*a*, 1960*b*; and Wallace, Nickell, and Bernard, 1961).

In Wisconsin, where the picture has been almost identical, minor differences in the mortality reports can be attributed to pressure exerted on operators by the State to finish spraying operations earlier in the spring. When elms on the University of Wisconsin campus were sprayed with DDT for the first time, Robin mortality on 61.2 acres was found to run at least 86 per cent (Hickey and Hunt, 1960*b*). After the second season of spraying, this figure was at least 85 per cent (Hunt, unpubl.). Careful census work in six residential areas that had been sprayed with DDT for 3 years in southern Wisconsin disclosed that their breeding-bird populations were 31–90 per cent lower than the average for five unsprayed residential areas (Hunt, 1960). Although these study areas were not randomly selected and therefore not indicative of average conditions, the indicated bird mortality due to DDT was significantly correlated with the number of elm trees sprayed per acre (Hickey and Hunt, 1960*a*). Where sprayed street elms numbered about 10 per acre, the drop in the breeding-bird population apparently was on the order of 90 per cent after 3 years of spraying. Where all the elms of an area (rather than just the street elms) are sprayed, densities of 3.1–4.8 trees per acre have been associated with Robin mortalities of an equally high magnitude (Wallace et al., 1961; Hickey and Hunt, 1960*a*).

At Shorewood, Wisconsin, Hunt (1960 and pers. comm.) could detect no difference between the bird population of an area mist-sprayed that spring and one mist-sprayed the previous fall. Bird-mortality differences attributable to other variables (like mist-spraying vs. hydraulic spraying, height of trees, etc.) have not been studied.

All the bird-mortality reports in the Middle West point to a consistent pattern when a full-scale use of DDT is launched to control this disease: The direct mortality is largely confined to April, May, and June. It seems to involve mostly breeding birds in Wisconsin; but a delayed spraying program (late April or early May) in a late cold spring can cause heavy mortality among wood warblers and other foliage gleaners (Wallace et al., 1961). The bird mortality is spectacular and easily observed during the first spring after spraying; it is still conspicuous but much less noticeable in the second spring; it almost escapes public notice by the third spring—when the bird population has been fully depressed. At this point, spring census work in three Wisconsin municipalities has shown that a mortality of 36 per cent was still occurring within a 6-week period during the nesting season (Hickey and Hunt, 1960*a*). The fatal ingress of birds into sprayed areas during the breeding season has been noted in both Michigan (Wallace, 1960*b*; Wallace et al., 1961) and Wisconsin (Hickey and Hunt, unpubl.) and apparently represents a drain on the songbird populations of nearby unsprayed terrain. About one-half of the bird mortality involves Robins. Although none of these urban-dwelling species is, in my opinion, in any danger of extinction at this time, the bird populations affected by this program have a high sentimental value because they enter so intimately into the daily lives of so many people.

It is impossible at this time to estimate with any accuracy how many birds have been fatally involved in this heavy use of DDT. Wallace's (1959) estimate of "millions" of Robins killed by DDT in DED programs is in turn based on an over-all estimate of 2 million acres of elms treated in the United States (George, 1959). In Wisconsin, we have been impressed with the fact that at least one Robin was apparently lost for every four elms sprayed on Hunt's (1960) study areas. Thus, if 1.5–2 million trees approximate the number now being sprayed with DDT in the Middle West, then about 375–500 thousand Robins may be initially lost when DDT is used to protect elms, and some lesser but unknown number is then lost each subsequent year as new birds move into the sprayed areas. Since the numbers involving other species of birds should be roughly equivalent to the number of Robins (Hunt, ibid.), it is possible that the initial loss in urban birdlife due to this type of DED control is on the order of ¾ to 1 million birds in this region. These estimates are very crude ones involving (1) a very risky extrapolation of Wisconsin mortality records to a much larger geographic area in which DDT is being used to control elm bark beetles, and (2) a very crude assumption regarding the number of trees being sprayed. Whatever the true extent of the loss really is, one may at least conclude that the wildlife-conservation problem here is very large.

Methoxychlor.—A third system of DED control involves the usual sanitation plus the use of methoxychlor (Whitten, 1958; Norris, 1961). This chemical has a very low toxicity to warm-blooded animals (Negerbon, 1959). When DDT is fed for 5 days to captive Robins, 50 per cent of the birds will die at a daily dosage of 110 mg./kg.; whereas a similar diet of methoxychlor at 3750 mg./kg. has failed to kill any of the birds (Hickey, Sacho, and Hunt, unpubl. MS). Usage of this insecticide in DED control has been restricted in the past partly by the price of the chemical and partly by uncertainties about its effectiveness in this program. After much research on the control of DED, Norris (1961) recommends the use of methoxychlor as a 12 per cent emulsion spray applied by mistblower in early spring before the emergence of buds. It is now being used by two communities in Illinois (Neely et al., 1960) and three in Wisconsin.

Conclusions on DED Control.—The use of DDT to control DED is clearly a threat to an important component of the birdlife in the Middle West. It is a relatively inexpensive chemical to purchase and a relatively convenient one to apply; but its use should be vigorously condemned where elm trees that are to be sprayed reach moderately high densities in this region. Conservationists should, however, recognize that the substitution of methoxychlor for DDT that has been applied in the past does not at once remove the DDT now in the soil . . . and that Robin mortality will continue until local earthworms no longer carry concentrations of DDT that are lethal to the birds eating them. Although at the present time there are no studies of the wildlife effects of methoxychlor under operational conditions, it appears that the tremendous urban elm population of the Middle West and its associated birdlife can both be preserved by vigorous tree-sanitation programs, with methoxychlor spraying carried out in spring on (a) the more valuable trees and (b) in those areas where elms have a relatively high density per acre.

Federal-state Programs

Federal eradication and suppression programs have in recent years been confined to imported insect pests. Co-operatively organized by the federal and state departments of agriculture, these programs have involved very large acreages, have taken on considerable importance in the public eye, and are bound to increase in the Middle West as more and more ocean-going vessels take advantage of the St. Lawrence Seaway and as more and more air terminals like O'Hare Field in this region receive aircraft direct from Europe (Simmonds, 1959). The wildlife-conservation problems, which are quite complex and varied, are illustrated in three examples:

Gypsy Moths.—The long history of efforts to eradicate this species in the eastern United States has recently been reviewed by Worrell (1960). This moth was found in Michigan in 1954, its previous western boundary having been eastern Pennsylvania. From 1954 to 1959 inclusive, 249,798 acres in Michigan were treated in an attempt to wipe out this pocket of distribution. These treatments, which involved 1 lb. of DDT per acre, should not importantly affect forest-dwelling birds, but the effects of 1 lb./acre on the birdlife of open terrain appear to be inadequately studied.

Japanese Beetles.—These insects have been steadily moving westward, and suppression measures have been taken in Michigan, Indiana, Kentucky, Illinois, Iowa, and Missouri. Up to 1960, these six states treated 96,000 acres in co-operation with the U.S. Department of Agriculture. The usual chemicals employed are granular aldrin, dieldrin or heptachlor, applied at 2–3 lb./acre. These hydrocarbons are far more toxic than DDT at such levels, and the wildlife losses have been considerable.

At Sheldon, Illinois, resident Meadowlarks (*Sturnella magna*), Robins, Brown Thrashers (*Toxostoma rufum*), Starlings (*Sturnus vulgaris*), Grackles (*Quisculus quiscula*), and Pheasants were virtually eliminated; so too were muskrats (*Ondatra zibethicus*), rabbits (*Sylvilagus floridanus*), and ground squirrels (*Citellus franklinii* and *C. tridecemlineatus*) (Scott, Willis, and Ellis, 1959). At Blue Island, Illinois, over 300 dead and dying birds were picked up in a 2-month period; 37 of these were banded birds (Bartel, 1960). Bartel's banding data suggest that the songbird mortality in his area was on the order of 80 per cent; his personal estimates, based on other criteria, were slightly higher. Among the curious side effects at Sheldon was a 160 per cent increase in the number of corn borers (Luckmann, 1960).

The reaction of the public to this federal-state program has been one of steadily increasing apprehension and emotion. This is not surprising since the program has gradually expanded to include urban and suburban areas. Although the mortality at Sheldon was thoroughly documented by a research team from the Illinois State Natural History Survey Division (Scott et al., 1959) and the wildlife losses labeled as "severe," an Illinois control official was asserting in 1960 that the Survey had found "no . . . serious damage being done to wildlife" (letter, 7 January 1960, S. J. Stanard to F. W. Zebell).

There is, of course, a subtle and important distinction between the words "serious" and "severe," but this is usually lost on the public, which is often far more informed about direct songbird losses than control authorities realize. The net effect of such statements is to inflame public opinion and to lower public confidence in control or eradication programs. Rightly or wrongly, the entire program is now challenged . . . and some highly technical questions are subjected to debate.

These questions involve such matters as the choice of insecticide, application rates, and extent of the area to be treated. Why did Illinois drop dieldrin and switch in 1960 to aldrin—one of the most toxic of all agricultural chemicals to game birds (Post, 1952; Dahlen and Haugen, 1954; DeWitt, 1955)? And if Illinois was really successful in treating 74,615 acres from 1954 through the spring of 1960, why were 38,914 still scheduled for treatment in the fall of 1960? These are questions which an enlightened citizenry is entitled to ask but not always able to judge. In the modern technological world, we still want the technical efficiency of managerial government with the traditional responsibilities of public servants in a democracy. What appears to be lacking in insect-control machinery of some states is an administrative realization of the emotional impact of modern insecticides on the public mind, an alertness to all the questions that are puzzling conservation-minded people, a willingness to admit that wildlife losses are taking place under certain conditions, and a sense of responsibility to show exactly how these losses are being kept to a minimum and why these losses are justified. When these are lacking, public fears regarding an entrenched bureaucracy are bound to mount.

One may conclude from this rather brief review that eradication and suppression programs require well-defined coordination of state conservation and state agriculture departments; and that there is a pressing need for alert extension teaching when a state prepares to co-operate with the federal government in a program of this type.

The Fire-ant Program.—This will long remain a classic example of how an insect problem can be mishandled at the administrative level. Amid all the furor, charges and counter-charges, it seems obvious that the U.S. Department of Agriculture did not clear its plans in advance with the Department of Interior and with the state conservation departments that were subsequently involved. Much less clear are three fundamental hypotheses on which the program has been based: (1) that the fire ant is indeed a costly pest, (2) that the initial application rates were selected on the basis of adequate research, and (3) that the Department's program can indeed eradicate the imported fire ant in the United States.

There seems to be little doubt that the wildlife losses associated with this program in its early stages (when dieldrin and heptachlor were used at 2 lb./acre) must have been very great (Baker, 1958; Clawson and Baker, 1959; Glasgow, 1958; Lay, 1958; Rosene, 1958); but it should be borne in mind that the insecticides were not being applied to a solid block of "27 million" acres and that the bird populations affected may regain their former levels in a period far shorter than some conservationists have predicted. One prominent game manager has said that it will take 25 years for Bobwhite Quail (*Colinus virginianus*) to recover from the fire-ant program. This view is, in my opinion, far too pessimistic. The Bobwhite has a high breeding potential, and it should be able to come back within 5 years after disappearance of the toxicant. The degree to which this period may vary is discussed below under Population-recovery Rates.

DeWitt, Menzie, Adomaitis, and Reichel (1960) have found that Woodcock are now incorporating dieldrin or heptachlor epoxide into their tissues soon after they arrive on the wintering grounds. Because the chlorinated hydrocarbons have a tendency to build up in a bird's gonads, some impairment of this species' reproductive efficiency is possible. The actual degree of probability is, however, unknown at this time. It does seem safe to conclude that the complex operations of the fire-ant program should be of interest and concern to sportsmen as far north as Minnesota, Wisconsin, and Michigan. This is especially true since DDT may now be depressing the reproductive success of Woodcock in New Brunswick where chemical residues from the fire-ant program are also beginning to appear in the tissues of this species (Wright, 1960). If the basic hypotheses of USDA regarding the fire-ant program are all true, then the wildlife loss may simply be a part of the price that society has to pay in the long run. If any one of the three hypotheses is false, then the USDA plant-pest machinery surely is in need of modification.

General Conclusions on Federal Programs.—The most impressive aspects of the recent federal programs are—from the wildlife ecologist's point of view—the vast acreages they can involve and the extreme wildlife hazard they develop when aldrin, dieldrin, or heptachlor are applied in a granular form at 2–3 lb./acre. When two such variables occur simultaneously, there will always exist the possibility that a species limited in distribution [like Kirtland's Warbler (*Dendroica kirtlandii*) in Michigan, the Golden-cheeked Warbler (*D. chrysoparia*) in Texas, and the Dusky Seaside Sparrow (*Ammospiza nigrescens*) in Florida] will be exposed to a federal program at a time when its repopulation rate is unequal to the occasion. Hence federal emergency programs will always contain an element of danger in the eyes of wildlife conservationists.

There are few conclusions that one may draw from these federally sponsored programs and the activities of state agencies co-operating in them. In general, the control agencies have been slow to admit that their programs can and do cause locally severe bird mortality, and conservation groups have been equally slow to realize that the affected bird populations will generally recover within a few years' time after disappearance of the toxicant. Amid all the public unrest, there is (1) a mounting apprehension that avian species with critically low populations may be irreparably reduced before conservation agencies are aware that a control program is underway and (2) an increasing suspicion that an entrenched federal bureaucracy is seeking to perpetuate or increase its empire (Cottam, 1958). This latter view, while often quite unfair to the dedicated public servants in government agencies, is not uncommon in other areas of our society; but a careful evaluation of such a hypothesis is quite outside the scope of the present review. What emerge from the abundant literature on this subject are (1) a growing realization that inadequate provisions exist in the federal government for collecting all the information and making it available to decision makers on major insect-control programs (Worrell, 1960), (2) an increasing awareness that state fish and game departments have no contact with the U.S. Department of Agriculture (Popham, 1960:60), and (3) a mounting conviction that decisions affecting the welfare of wildlife should not be left entirely in the hands of regulatory entomologists at either the federal or state level (Turner, 1959).

Mosquito Control

Although the broad ecological effects of mosquito control received much attention when DDT was first introduced (Erickson, 1947; Bishop, 1947; Tarzwell, 1947, 1950; Scudder and Tarzwell, 1950), wildlife biologists have not evaluated many developments in this program that have taken place within the past decade in the United States. By 1952, mosquitoes in some parts of the country were exhibiting a high level of resistance to all the chlorinated hydrocarbons, and mosquito-abatement districts were turning to organic phosphates like EPN, chlorthion, malathion, and parathion (Grieb, 1957). In various countries, physiological resistance to the chlorinated hydrocarbons had been confirmed in more than 20 species by 1959, and in more than 37 by 1960; and in California some resistance to malathion and parathion is now reported (Communicable Disease Center, 1960, 1961). The organophosphus compounds differ greatly in their toxicity to warm-blooded vertebrates, but none of them have been studied as they are used in mosquito-control programs. A national survey of mosquito-control agencies in January 1956 showed DDT to be the compound still most commonly relied upon, with substantial use reported for BHC, malathion, pyrethrum, and dieldrin (Ginsburg, 1956). Although Illinois now spends over $800,000 annually in 17 mosquito-abatement districts covering nearly 1,000 sq. miles (Lopp, 1958; Boulahanis, 1959), the Middle West does not have—for the most part—the highly organized mosquito-control agencies found on both the West and East coasts, and DDT still appears to be the insecticide most commonly used in this region to control mosquitoes.

Adult-mosquito Control.—According to Quarterman (1957), there are no such things as standardized formulations and application rates in this program; these vary throughout the United States according to the species of mosquito involved, the ecology of the area to be treated, annual changes in the weather, and differing opinions of the operators. In the United States, DDT is used most commonly as a 5 per cent solution in fuel oil, applied at approximately 0.5 lb. per acre (ibid.). This application rate is considerably higher than that currently being recommended for adult mosquito control in Wisconsin (E. H. Fisher, pers. comm.). Couch (1946) has reported the disappearance of insect-eating songbirds when a lowland forest in Illinois was sprayed at monthly intervals with DDT at 0.5 lb./acre. In this case, the spraying did not begin until August 8 (when the nesting season was almost completed), and there is a strong possibility that local songbirds reacted to depleted food supplies by moving off the sprayed area. (During the nesting season, their movement would be more localized, and—if the application was more frequent than monthly—some loss of reproductive efficiency might take place.) In another Illinois study, applications of DDT mist at 1 lb. per acre were begun on 23 June in a mixed prairie and forest and on 22 July on a wooded river bank (Ross and Tietz, 1949). Although the birdlife was reported as not visibly affected, any such effects would be very difficult to measure; and there was clearly a change in the insect food supplies available to birds.

It is difficult to estimate the bird mortality taking place at Maple Bluff, Wisconsin, where some 20 mosquito-fogging operations in the entire village averaged 0.18 lb. DDT/acre in 1960 and where each acre got 3.5 lb. of DDT during the entire mosquito-fogging season (Dicke, 1960). Although this total amount of the insecticide should be sufficient to set up the lethal earthworm-chain reaction for Robins, discovered by Barker (1958), the Robin mortality in this community was spectacular shortly after the area was first subjected to DDT to control Dutch elm disease (Hickey and Hunt, 1960*b*). This loss could scarcely have resulted if mosquito control had seriously depressed the breeding-bird population in previous years. Wallace (in litt.) has encountered DDT-stricken birds following a mosquito-control operation in Michigan. If Midwestern adult-mosquito control techniques are as variable as Quarterman (1957) says they are nationally, local variation in bird mortality due to this program surely is possible. In Illinois, where mosquito-control work dates back to 1921, the area included in organized abatement districts now represents about 1.67 per cent of the total acreage in the state (Boulahanis, 1959). In Wisconsin, local fogging for adult mosquitoes is being carried out far more frequently than entomologists feel is necessary (R. J. Dicke and E. H. Fisher, pers. comm.).

Adult-mosquito control in the Middle West appears to have a variable, rather uncertain, and quite possibly minor effect on birdlife. Wherever possible, it should be (1) localized, (2) carried with minimum application rates, (3) authorized only when conditions really require it, and (4) delayed until the conclusion of the breeding-bird season.

Mosquito Larviciding.—Elsewhere in the United States, modern larviciding has long been regarded as having rather little effect on birdlife. Good control of Culicine and Anophaline mosquito larvae was initially obtained with DDT repeatedly applied at 0.1–0.25 lb./acre (West and Campbell, 1952). In South Carolina, 12 routine larvicidal treatments by airplane from 28 May to 5 September at 0.1 lb. DDT/acre are reported to have reduced mosquitoes, deer flies, and sand flies in numbers, but to have no observable over-all effect on other terrestrial insect populations (Scudder and Tarzwell, 1950). Repeated applications in South Carolina also had no known effect on birdlife in terrestrial habitats (Erickson, 1947). Dicke's (1960) report of 0.5 lb. DDT/acre being used from 1 to 21 times per season for larval-mosquito control at Madison, Wisconsin, carries the implication (I think) that insect food for some birds may be reduced. In this instance, however, the larviciding is carried out on "high grass" and temporary water, and (it should be stressed) permanent marshes in this area are avoided. The effects (if any) on birds in this city seem likely to be confined to a few species like Song Sparrows (*Melospiza melodia*), Vesper Sparrows (*Pooecetes gramineus*), and Meadowlarks; since only 2.6 per cent of the city's area is involved, the over-all effect on Madison's birdlife is likely to be slight. Until additional data are gathered on the actual larviciding techniques of other communities, the wildlife effects of this program will remain unknown. The relative rarity of aircraft applications in the Middle West and the emphasis on treatment of temporary pools of water, rather than permanent ones, seem to me to reduce the potential hazard of mosquito-larval control to wildlife in this region. In other states, residual larvicides are now being applied at rates that certainly should be investigated by wildlife ecologists: DDT at 3–10 lb./acre, heptachlor at 5 lb./acre, and malathion at 3 lb./acre (Communicable Disease Center, 1961).

Research Needs.—The ecology of modern mosquito control in the Middle West is in many ways little known. Information is needed to determine the variation in amount of DDT now used by governmental agencies, by government contractors, and by private landowners for both larval- and adult-mosquito control. It is needed also to determine not only the size and shape of the areas now being subjected to DDT but also the density of wildlife populations exposed in each habitat. It is further needed to clarify both the short-term and the long-term effects of frequent spraying on key populations of other insects that are important to high-density bird populations.

OTHER FEARS

Impairment of Reproductive Success.—In the laboratory, pheasants and quail chronically exposed to a diet containing sublethal amounts of chlorinated hydrocarbons have suffered a marked reduction in reproductive efficiency (DeWitt, 1955; Genelly and Rudd, 1956). This has led wildlife conservationists to fear that many birds may survive a sublethal exposure to insecticides but still suffer a marked loss of eggs or surviving young as a result. This is an extremely difficult phenomenon to detect and verify in the field, but Wright (1960) has obtained circumstantial evidence that Woodcock are thus affected by spruce budworm spraying in New Brunswick. Depressed reproductive success in the Wild Turkey (*Meleagris gallopavo*) has also been reported 1 year after fire-ant eradication in Wilcox County, Alabama (Clawson, quoted by DeWitt and George, 1960). Genelly and Rudd (1956) suggest that the phenomenon may occur in pheasants that attempt to nest in commercial orchards where 40–60 lb. of DDT may be applied annually on each acre. It does not, of course, follow that the diet and exposure of wild birds are similar to that of the captive birds alluded to in the above experiments. What exists as a possibility has frequently been taken by conservationists to be a probability. It is extremely difficult to recommend or to recognize what is the conservative position that society should take in this matter. Among the facts that research workers could furnish to clear up this confusion are chemical analyses of the insecticide content of the gonads of birds killed each spring at TV towers in the northern tier of states. These birds presumably represent randomized samples of bird populations. If the gonads and other organs proved to have no traces of insecticides, the argument that the particular species sampled tend to pick up critically important amounts of DDT during their migratory and wintering periods would tend to collapse. If insecticides were present, the amounts found would then have to be correlated with those known in the laboratory to impair reproductive efficiency.

Disruption of Food Chains.—The destruction of food resources brought about by insecticides is potentially a major hazard to birdlife, as many writers have pointed out. This danger is a function of a great many variables:

(1) the size, shape, and ecological characteristics of the area treated (small or narrow areas are least hazardous; self-contained aquatic areas are apt to hold the toxicant longest);
(2) the toxicity and residual life of the chemical used;
(3) the rate, manner, and frequency of application;
(4) interspecific and seasonal differences in the mobility of animals (swallows can readily forage elsewhere; but during the nesting season some birds are confined to areas less than 1 acre in size); and
(5) the life-history characteristics of the food organisms involved (some populations recover rapidly from contact with an insecticide, others much more slowly; earthworms can concentrate the toxicant).

There is no doubt that food supplies of some birds are quite radically changed by insecticides; but the actual effects on bird-population levels, reproductive success, and life expectancy have not been measured. This entire phenomenon requires further study in those treated areas where birdlife exists in moderately to fairly high densities. In the Middle West, the problem is restricted by the tendency of farmers to use insecticides on cropland where fence rows have virtually disappeared and where the breeding-bird population is now quite low. Attempts to work out the effect of an insecticidal treatment on a whole ecological system have seldom been carried out. This type of research requires highly organized team work, and it is beset by sampling problems that are often quite difficult to resolve.

Delayed and Long-term Effects.—The persisting effects of insecticidal treatments vary widely. Some chemicals are, of course, deliberately selected in control projects for their short residual life, while others may be applied at rates sufficient to have an insecticidal effect for as long as 3 years. As this latter effect was initially incorporated into the fire-ant program, the spring die-off of songbirds 1 year later (Baker et al., quoted by DeWitt and George, 1960) was not unexpected. Barker's (1958) finding that Robins began to die 1 year after foliar spraying of DDT throws new light on this general problem. This research, which incriminated the earthworm as the carrier, has obvious implications in Woodcock ecology; but the phenomenon has yet to be repeated under controlled experimental conditions.

After 10 years, experimental turf plots in Ohio have contained 11–18 per cent of the DDT originally applied to them, the rate of disappearance being inversely proportional to the initial concentration (Lichtenstein, 1957). Among application rates studied in this experiment, turf receiving 12.5 lb./acre in 1945 still contained 1.4 lb./acre in its upper 6-in. layer in 1955. The application rate used here on turf only once was considerably less than the 23.6 lb./acre and the 17.2 lb./acre that Hickey and Hunt (1960*a*) have calculated for DDT used on trees on University of Wisconsin and Shorewood (Wis.) study areas in 1959. Although soil type and other factors also influence the persistence of an insecticide in the soil (Lichtenstein, 1958; Lichtenstein and Schulz, 1959), it seems possible that Robins (which apparently constitute one-half of the nesting suburban songbirds in the Middle West) may be affected for some time after DDT is no longer used in these communities. At the present time, however, there are no adequate data correlating the amount of DDT applied to a tree during the dormant season and the amount of this insecticide that falls to the turf below.

GENERAL COMMENTS

BIOLOGICAL VS. CHEMICAL CONTROLS

Following Koebele's dramatic success in controlling cottony-cushion scale, there has been a continuous effort to find parasites, predators, and diseases that would control other insect pests (Martin, 1940). According to Clausen (1952), at least 30 major insect pests have been fully controlled by this method in one or more countries; and substantial reductions appear to have been brought about in the infestations of a much larger number. These successes have not been easily attained. At least 40 species were tested in California before black scale could be crossed off the list of serious citrus pests. The U.S. Bureau of Entomology's search for an effective enemy of the gypsy moth began in 1905 and lasted with some interruptions until the 1920's. Although some success has been reported in this particular search (Hawley, 1952), the gypsy moth was the subject of large-scale spraying in 1956–58. Of about 390 insect predators and parasites introduced and deliberately colonized in the continental United States, only 24 per cent are now established (Clausen, 1956). In general, climatic factors have greatly complicated the biological control of insects. Chemical control has one signal advantage in the eyes of entomologists; it can be counted upon to work in a wide variety of climates.

Companies like Roehm & Haas, Merck, Bioferm, and Stauffer are all reported to be active in the development of biological mechanisms to control insects. Much of the industrial approach appears to be confined to *Bacillus thuringiensis* to kill moth worms. The USDA is, of course, active in this field. Its recent eradication of the screw-worm fly in the Southeast now seems to be assured, and must be ranked among the great triumphs of modern technology. The recent synthesis of the sexual attractant of the gypsy moth (USDA news releases 964-60 and 2953-60) marks another important breakthrough. The department, however, has had virtually the same research budget for the past 10 years (under $5,000,000 annually). Since the biggest impetus for the development of biological controls should be here, and since inflation has certainly affected this budget throughout the decade, one may wonder about the encouragement now being given to research on biological mechanisms in the United States. It has been said that "the research program in economic entomology is out of balance" (Smith, 1946) and, with some notable exceptions, biological control methods in the United States are not being exploited on a wide scale (Steinhaus, 1960). The possibilities for biological control still remain encouraging (Pickett, 1959; Simmonds, 1959). If wildlife-conservation organizations really want to see this research increased, they may well have to go to their representatives in the Congress and actively work for an increase in the USDA appropriation for this type of work.

One of the most confusing aspects of Japanese beetle programs to the layman centers around the concept that a proven biological control (type-A milky spore disease) is being neglected in favor of the chemical approach in the Middle West. This view neglects the known life-history facts of the bacterium and the persisting difficulty of propagating *Bacillum popilliae* under artificial conditions prior to its sale to governmental agencies and to the general public. At the present time, the speed with which milky spore disease can be built up in a new locality directly depends upon the density of Japanese beetle grubs that are present (Hawley, 1952). This speed does not seem to be a function of closely related white grub populations, although the bacterium has been found in some June beetles. In short, milky spore disease represents an effective control of well-established Japanese beetles; but it is not known to be a barrier to geographic extensions of the species' range, and it has no place at this time in an eradication program. A state like Wisconsin, which has already had its first occurrence of this pest, cannot build up a milky spore population in advance of its host.

POPULATION-RECOVERY RATES

Among the intellectual factors contributing to our present confusion regarding insecticides, little attention seems to have been given to the rates or periods of time required by birds to repopulate heavily sprayed areas. Aside from food-chain and reproductive phenomena about which relatively little is yet known, the insecticide-wildlife relationship roughly breaks down into three types: (1) little or no wildlife mortality where the insecticide is lightly applied and then only as a one-shot affair; (2) considerable mortality where a highly toxic chemical is applied only once as an eradication measure (real or alleged); and (3) considerable mortality where insecticides are repeatedly applied in fairly high concentrations. Forest-insect work in the U.S. is an example of the first; Japanese-beetle and the initial fire-ant programs are examples of the second; Dutch-elm-disease control (and possibly orchard spraying) are examples of the third. The response of bird populations to these latter two types is the subject of research that is only now getting underway; but some generalized remarks on avian repopulation phenomena can be made at this time.

As Mills (1959) has pointed out, population-recovery rates for a given species will obviously vary (1) from year to year, according to the weather, (2) with the reproductive capacity of each species, (3) with its mobility, (4) with the level to which the species has been reduced, (5) with the existence of nearby habitat carrying good densities of the same species, (6) with the size of the tract to be repopulated, (7) with the persistence of the insecticide that has been used, and (8) with the relative toxicity of this chemical or its breakdown products.

It is a truism in both physics and biology that nature abhors a vacuum. Whenever an insecticide has depleted a bird population, new birds will move in to take advantage of the vacated habitat. This can be counted on to take place in Type 2 programs like eradication and in Type 3 programs like annual DED control. In Type 3, nearby unsprayed habitats will annually feed birds into the sprayed area, which thus serves as a death trap. During the breeding season of 1959, Wallace et al. (1961) had a high count of 22 Robins on the Michigan State University campus; but a total of 45 Robins were picked up or reliably reported there as dead or dying. Ingress here is clearly indicated.

Under conditions of catastrophe not involving an insecticide, a breeding-bird population like that of the Eastern Bluebird (*Sialia sialis*) may take up to 10 years to return to its former density over an area as large as New England (Forbush, 1929:419–420), but in areas as small as 40 acres, the recovery may be effected in a matter of weeks (Stewart and Aldrich, 1951; Hensley and Cope, 1951). There are no facts available that cover all the eight variables listed above; but, other things being equal, rapid recovery is apparently the normal thing in common, healthy, and vigorous species of birds (Griscom, 1941). This is a consideration that wildlife conservationists often fail to take into account in the evaluation of insecticidal programs carried out as eradication measures.

NATIONAL POLICY AND INSECTICIDE-WILDLIFE RELATIONSHIPS

From the present review of the effect of insecticides on both migratory and non-migratory birdlife, it is obvious that—despite all the unknowns still to be resolved—certain uses of insecticides do have broad, lethal effects on bird populations. These effects cannot be traced to carelessness in the field, or to accidents, or to instances of outright experimentation. National policy in respect to these phenomena is still in a state of evolution. I think it can be safely said that the United States has no formal and consistent policy regarding the protection that Americans are to give all forms of birdlife. It does have a body of presidential proclamations, congressional acts, and administrative decisions that, within the past 60 years, have to some extent formalized public attitudes and governmental responsibilities. The proclamation approach, extensively used by Theodore Roosevelt, did much to set aside portions of the public domain as parks, as reservations for colonial-nesting birds, and as game reserves. The congressional approach, made possible by the 1916 treaty with Great Britain, removed most migratory birds from the game list. Although this technique involved the elementary use of prohibition, it was a landmark in the development of a national policy regarding birdlife. In recent decades, the Congress has been most active in expanding the federal government's responsibilities toward migratory game birds, but congressional thinking on nongame birds has largely been restricted to budgetary support of federal research projects on such aspects of conservation as wildlife diseases and the effects of pesticides. Thus the research character of the U.S. Fish and Wildlife Service has—quite apart from the waterfowl problem—been the focus of a slowly developing national policy with respect to birdlife. The administrative decisions that have crystalized national policy on nongame birds have been many. The U.S. Fish and Wildlife Service has exercised a major responsibility for the Whooping Crane (*Grus americana*), and the U.S. Forest Service has done the same for the California Condor (*Gymnogyps californianus*). Secretary Seaton's decision not to allow mineral exploration in Condor terrain was an important landmark in the evolution of national policy; State Department pressure, sparked by an official protest from Canada, was even sufficient to modify activities of the military establishment in order to preserve the wintering grounds of the Whooping Crane.

Administrative recognition of the importance of pesticide research developed at the federal level during the 1930's when Cottam, Uhler, and Bourn investigated the ecological effects of mosquito control on the Atlantic Coast. Service studies were greatly expanded in the 1940's when DDT became generally available for public use. Research administrative leadership was, in effect, formally approved by the Congress. In 1960 the Congress went beyond the requests of the executive branch of the government in further expanding the Fish and Wildlife Service budget for research on pesticides.

Thus national policy with respect to songbirds is continuing to evolve; but its outlines are still vague and contradictory: Without a special permit, you cannot pick up and take home a road-killed Baltimore Oriole (*Icterus galbula*); you can generally with impunity, however, cut down a tree containing an oriole nest full of young. You cannot shoot a Snowy Egret (*Leucophoyx thula*), but you can drain off a marsh on which a whole colony of egret nestlings may depend for food. You cannot shoot a Robin, but you can kill it with an insecticide. In general, national policy holds that the economic interests of man supersede the survival interests of animals, but the federal government appears to exercise at least a research responsibility to mitigate the impact of economic developments upon the wildlife of the country. That our society does make exceptions to the overwhelming rule of economics is evident in our perpetuation of parks that have great sentimental or aesthetic value in spite of their tremendous worth as real estate. (Central Park on Manhattan Island is one example.) Americans may be quite pragmatic; but they are also sentimental . . . and some unconscious development of a wildlife ethic is taking place.

In public-health matters in the United States, national policy places the finger of guilt on a new food chemical until industry has demonstrated its innocence—and the innocence of its breakdown products. In the pesticide-wildlife field, the chemicals are—in effect—nearly always deemed officially to be innocent until proven otherwise. There is no organized system set up for testing the wildlife effects of new pesticides prior to, or even after, they are placed on the market; nor is there any agreement yet as to how this responsibility is to be shouldered. To some extent, the Congress has looked more and more to the Fish and Wildlife Service to plug this gap. It is hardly possible that the Service can ever do this alone, but the magnitude of the entire problem is not yet clear. Most states, for instance, do not even have statistics regarding the total amount of various insecticides used within their borders for agriculture.

THE DECISION-MAKING PROCESS

Decisions on the use of insecticides in this region are made by landowners, municipalities, counties, states, and the federal government. The degree to which wildlife-conservation interests participate in these decisions varies greatly.

At the landowner's level where farmers, gardeners, and suburbanites are so much involved, wildlife-conservation thinking seldom seems to enter into the decision-making process. In general and at the moment when these decisions are made, the public does not have ready access to information on the wildlife effects of the various application rates that are possible.

This situation may prove to be more and more hazardous to suburban wildlife. (Its public-health aspects are outside the scope of this review.) There is nothing at this time to prevent a landowner from oversaturating his property with DDT to control adult mosquitoes (although 0.1 lb. per acre may suffice), and the resulting hazard to nesting birds then becomes a function of the number of properties that are blocked in during the course of this process. (Excessively frequent use of DDT is, of course, one way to build up resistant strains of mosquitoes. At the present time, no such strains are known in the Middle West, and any contemporary prediction of their future appearance is complicated by the essentially local character of adult-mosquito control in this region.) The use of chlordane to kill crab grass is another potential hazard to suburban wildlife, but no ecological research has been carried out on this technique and its side effects, especially those on local Robins.

The private ownership of large blocks of forest land involves an entirely different pattern of decision making. Here there is always the possibility that either the state or both the state and the federal government will recognize the insect outbreak as a public danger and carry out a control program in which subsidies toward the landowner's share in the spraying are an important consideration. Quite apart from any state regulations regarding a permit to spray, economic interest thus dictates that technically trained foresters and entomologists enter into the decisions regarding the use of insecticides on privately owned forest land.

In general, wildlife interests have had in the past only a minor role in decision making at the municipal level. An April cut-off date for Dutch-elm-disease spraying in Wisconsin (jointly set up by the state conservation commission, the state board of health, and the state department of agriculture) may well have reduced the hazard to May migrants; these were conspicuously affected by late spraying operations in Michigan in the spring of 1956 (Wallace et al., 1961). Public interest in the matter seems to have encouraged three municipalities in Wisconsin and two in Illinois to substitute methoxychlor for DDT in spring. Thus, the weight of public opinion in some states is somewhat in advance of regulations set up by a state pesticide review committee. This occurs despite a frequent failure of government authorities to acquaint the public with the wildlife hazards of insect-control programs. Proposals to create or strengthen a state pesticide-review board or committee have recently been the subject of legislative consideration in Michigan, Illinois, and Wisconsin. Review boards may indeed be helpful in some states where control agencies have consistently refrained from consulting with conservation departments, but their authority is often restricted (as in Connecticut, to aerial application; or in Wisconsin, to forest and noncrop spraying). The wisdom of their decisions will also be limited by the paucity of research data that are available (as on the effects of mosquito-control operations on urban birdlife). Co-ordination of government agencies now having quite separate functions is clearly a current need. Each state could also profit by some long-range planning jointly carried out by agronomists, plant pathologists, pollution experts, public-health authorities, entomologists, foresters, and fish and wildlife biologists.

At the federal level in the United States during the 1940's, close co-operation in research featured the many efforts of the old Bureau of Entomology and Plant Quarantine (in the Department of Agriculture) and the Fish and Wildlife Service (in the Department of Interior) to understand the complex side effects of DDT. This co-operation seems to have gradually disappeared, and at least until 1961 the present Agricultural Research Service did not enjoy a close working relationship with the Bureau of Sport Fisheries and Wildlife in the Interior Department. During the past decade, when ARS was able to set up large-scale programs involving granular applications of aldrin, dieldrin, or heptachlor, the absence of an efficient interdepartmental memorandum of agreement significantly contributed to public controversy. Such an agreement was worked out during the past year; but as late as 1960 ARS flatly refused to deal with state fish and game departments, as Congressman Dingle brought out in a public hearing (Popham, 1960:60). Although it is true that most game populations will recover after a heavy application of (say) aldrin has disappeared, no written-out arrangements exist to enable a state conservation department to plan locally closed hunting seasons and to inform sportsmen why such steps are necessary. This conflict of interests in the United States has a parallel in Canada where spruce budworm spraying appears to be threatening local populations of salmon. There, however, a federal inter-departmental review committee represents the agencies responsible for forest, fish, and wildlife resources (Preble, 1960), and co-ordinated efforts to resolve a difficult problem have now led to a new use of DDT at ¼ lb. per acre (Webb, 1960).

WILDLIFE-CONSERVATION NEEDS

If society is to succeed in minimizing the impact of insect control upon wildlife populations, it will have to delegate specific authority for certain jobs, co-ordinate the technical knowledge now available, and find the funds to use the full potential of scientific research in resolving the problems, both real and alleged, that now face our developing technology.

Virtually all of the ecologists who have reviewed the over-all pesticide-wildlife problem emphasize the lack of factual information on this phenomenon, and they point out specific areas that require research (Rudd and Genelly, 1955, 1956; George, 1957; Leedy, 1959). These research needs are critical and require no itemization here, although the need for a team approach cannot be over-emphasized. Ecologists, however, are not political scientists, and their papers deliberately avoid recommendations that have political overtones (using politics in the best meaning). This has left a serious gap in conservation thinking. I feel no better equipped than my colleagues to fill this gap, and I would prefer to delineate needs rather than recommendations. These needs involve both federal and state responsibilities. They appear to apply to the Middle West as well as to other parts of the United States.

NATIONAL NEEDS

(1) As new insecticides continue to come into the market, the responsibility will have to be fixed for determining their general wildlife toxicity and hazard. This means an expanded budget for either industrial, federal, or federally sponsored research. It also means a national board of review and some expansion of our present labeling system. It does not mean a Miller-like amendment which arbitrarily eliminates the agricultural use of compounds that exceed some established tolerance. It does mean that new insecticides should be identified as to their probable effect on a limited number of wildlife species under certain specified conditions. There is a widespread feeling among wildlife conservationists that the Congress should place the responsibility for this research on the manufacturer who releases a new economic poison on the market. To some extent, the Congress has already done so (George, 1957): the Federal Insecticide, Fungicide, and Rodenticide Act states that every manufacturer must plainly mark his insecticide with an appropriate statement of precautions to prevent injury to man and domestic animals, fish and wildlife. Under this legislation, the U.S. Department of Agriculture is given discretionary responsibility in the registering of new compounds. The system is not effective, as wildlife conservationists see it, and a realistic appraisal is now needed. This appraisal could well be carried out by the new Committee on Pest Control and Wildlife Relationships that has been set up by the National Academy of Sciences and the National Research Council.

(2) Some parallel system should be worked out to cover the more toxic compounds that now are widely used. Field studies are needed not only on the short-term, wildlife-mortality effects, but also on repopulation rates, long-term reproductive effects, and food systems. This expansion of ecological investigations will surely require an increased budget for the U.S. Fish and Wildlife Service. Where elaborate facilities (like pens and cage equipment for toxicological studies) are required, the Service will do well to carry out the research itself. Where field investigations are needed under a variety of conditions, the Service will have to set up research contracts with agricultural experiment stations, its own co-operative wildlife research units, and other colleges and universities. This possibility is further discussed under (6) below.

(3) The Agricultural Research Service of USDA should get budgetary encouragement to expand its research work on insect-control methods that will affect pest targets without disrupting entire food-chains and affecting wildlife populations.

(4) The National Science Foundation and other agencies encourage and subsidize intensive studies of food-chains as they are affected by our most widely used pesticides. These are difficult investigations to carry out, involving (as they do) teams of specialists capable of working together on both vertebrate and invertebrate animal populations. A co-ordinating committee of the National Research Council or the Ecological Society of America is probably needed to encourage and integrate this type of work which,

at least initially, could be restricted to natural areas and a few very typical types of pesticidal usage.

STATE NEEDS

(5) State legislatures should inaugurate statistical systems that will clearly show the extent to which the more important insecticides are being used within their borders. These statistics should include the crops and land uses involved, the chemicals and rates of application used in each type, the method and frequency of application, and approximate acreages. Some provision should be made for testing the accuracy of the data so compiled. California's present system is often regarded as an appropriate model; but Dicke's (1960) compilation of Wisconsin statistics is the only summary that I have seen clearly picturing the use of agricultural insecticides in a given state—in terms that are meaningful to ecologists and conservationists. These statistics need only be compiled about once every 5 years in order to show trends. They could well be made a responsibility of each state department of agriculture.

(6) Agricultural experiment stations should co-ordinate their research on the actual application rates that are being employed for the major poisons in each region, giving attention not only to immediate but also long-term wildlife effects. Wildlife ecologists attempting to carry out research on insecticides in Illinois, Michigan, and Wisconsin frequently report that they are restricted by a lack of state funds to carry out their investigations. Special federal subsidies provided by the Congress are certainly needed to conduct this work on migratory birds, but studies of pesticidal effects on non-migratory game should be financed by each state.

(7) Agricultural extension specialists should assume a greater responsibility in explaining federal and state insecticidal programs to the general public both urban and rural. They should be prepared to explain the reasons for these programs, to predict what wildlife losses are expected, and to show how efforts are being made to reduce these to a minimum. This is not a criticism of the Agricultural Extension Service, but rather a vote of confidence that it can fill a gap that now exists. The confused state of public opinion is to some extent the result of overspecialization in both research and control operations. If the Service is willing to help its men to train themselves along broad ecological lines, it can do much to educate the public on the complex, interlocking problems that it is facing. In many state conservation departments, extension specialists can also greatly contribute to the solution of this problem.

(8) In states where interdepartmental liaison is traditionally poor, legislatively created boards of review may be required to permit the state conservation department (and also the department of health) to participate in decisions on mass-spraying programs. Connecticut's regulatory committee is a much-quoted example, but its powers surely require expansion. My review did not go into this aspect of the problem.

(9) Legislative Reference Bureaus (or their equivalent) should have standing pesticide advisory committees to (a) inform each legislature of new pesticide developments that may affect not only public health but also the wildlife resources of the state, (b) review state trends in pesticide usage every 5 years, and (c) recommend practical procedures in the control of pesticidal use that are appropriate. In some states, as in California, legislation may require the licensing of trained personnel for the application of the more toxic chemicals now on the market. At the federal level, the National Research Council has recently established an advisory committee on pesticide-wildlife relationships. Its counterpart almost surely is needed at the state level, too.

SUMMARY

In the Middle West, few data are available on the acreages now sprayed for mosquitoes, on the variations in application rates, and on the long-term effects of this type of control. Large-scale, orchard-insect control is potentially more hazardous to wildlife, but is equally unstudied in this connection. Forest-insect pests now appear, with one possible Canadian exception, to be controlled with little or no apparent loss of birdlife. Dutch-elm-disease control has had very serious urban wildlife effects in the Middle West, but the substitution of methoxychlor for DDT in the spring promises relief from this problem. Programs of the U.S. Department of Agriculture to suppress Japanese beetles in this region and to eradicate fire ants in the South have been associated with marked effects on songbird and gamebird populations; it appears likely that most of these populations will recover within a few years after disappearance of the insecticide, but federal programs will remain a threat to bird species of limited distribution. Agricultural use of insecticides has not been adequately studied for its effect on wildlife, but severe bird mortality on cropland treated in Wisconsin may be mostly confined to about 20,000 acres where apples and cherries are grown.

Reproductive efficiency has been markedly lowered as the result of sublethal ingestion of chlorinated hydrocarbons by laboratory birds; and this has led conservationists to fear that many wild bird populations may be insidiously depressed by modern insecticides. It is also feared that the disruption of food chains may also be hampering birdlife today. Both hypotheses are quite difficult to test in the field, although reproductive failures in Woodcock and Wild Turkey are now reported to be associated with use of insecticides in New Brunswick and the South. In general, control agencies have displayed some slowness in admitting the effect of insecticides on birdlife, and conservationists have been equally slow to admit the population-recovery potential of bird species killed off in emergency insect-eradication programs.

National policy regarding nongame birds has been gradually developing throughout the present century. At the present time, the U.S. Congress is interested in lessening the impact of modern insecticides on wildlife, but no satisfactory system has evolved to identify the wildlife hazards of new insecticides that come on the market, and state conservation agencies do not participate in all the major insect-control decisions of the U.S. Department of Agriculture. Research on biological control in America is not being fully exploited in the United States, and budgetary encouragement of the Agricultural Research Service along these lines could be pushed by conservationists. Intensive ecological research on food-chain systems could also be expanded with federal funds that are now available, but some responsibility to encourage and organize this difficult work will have to be assumed by the National Research Council or a similar agency.

State governments should inaugurate statistical systems on pesticides, co-ordinate research by agricultural experiment stations on the field use of the major poisons, expand extension teaching in this field, integrate interdepartmental interests and goals, and create standing advisory committees to anticipate new problems.

LITERATURE CITED

Adams, L., M. G. Hanavan, N. W. Hosley, and D. W. Johnston
1949 The effects on fish, birds and mammals of DDT used in the control of forest insects in Idaho and Wyoming. *J. Wildl. Mgmt.*, 13(3):245–254.

Baker, M. F.
1958 Observations on effects of an application of heptachlor or dieldrin on wildlife. *Proc. Twelfth Annl. Conf. Southeastern Assn. Game and Fish Comm.*, pp. 244–247.

Barker, R. J.
1958 Notes on some ecological effects of DDT sprayed on elms. *J. Wildl. Mgmt.*, 22(3):269–274.

Bartel, K. E.
1960 "Let us (s)pray" some more. *Inland Bird Banding News*, 32(3–4):37–39, 44–45.

Benjamin, D. M.
1960 A brief history of the use of insecticides in Wisconsin forests and nurseries. Dept. Entomology, Univ. Wis. 7 pp. (mimeo.)

Benjamin, D. M., P. W. Smith, and R. L. Bachman
1959 The European pine shoot moth and its relation to pines in Wisconsin. *Wis. Conserv. Dept., Tech. Bull.* No. 19, pp. 7–23.

Bigger, J. H., and R. A. Blanchard
1959 Insecticidal control of underground insects of corn / A report of a 5-year study. *Univ. Ill. Agr. Expt. Sta., Bull.* 641. 28 pp.

Bishop, E. L.
1947 Effects of DDT mosquito larviciding on wildlife. III. The effects on the plankton population of routine larviciding with DDT. *Publ. Health Repts. (U.S.)*, 62(2):1263–1268.

Boulahanis, A. J.
1959 Mosquito control in Illinois. *Mosquito News*, 19(1):23–25.

Clausen, C. P.
1952 Parasites and predators. Pp. 380–388 *in* Insects / The yearbook of agriculture. U.S. Govt. Printing Off., Wash., D.C. 780 pp. + 72 pl.
1956 Biological control of insect pests in the continental United States. *U.S. Dept. Agr., Tech. Bull.* 1139. 151 pp.

Clawson, S. G., and M. F. Baker
1959 Immediate effects of dieldrin and heptachlor on Bobwhites. *J. Wildl. Mgmt.*, 23(2):215–219.

Communicable Disease Center
1960 Public health pesticides for mosquitoes . . . . *Pest Control*, 28(3):9–29.
1961 Public health pesticides for mosquitoes . . . . *Pest Control*, 29(3):9–27.

Cottam, Clarence
1958 A commentary on the fire ant problem. *Proc. Twelfth Annl. Conf. Southeastern Assn. Game and Fish Comm.*, pp. 257–260.

Couch, L. K.
1946 Effects of DDT on wildlife in a Mississippi River bottom woodland. *Trans. N. Am. Wildl. Conf.*, 11:323–329.

Dahlen, J. H., and A. O. Haugen
1954 Acute toxicity of certain insecticides to the Bobwhite Quail and Mourning Dove. *J. Wildl. Mgmt.*, 18(4):477–481.

Dambach, C. A., and E. E. Good
1940 The effect of certain land use practices on populations of breeding birds in southwestern Ohio. *J. Wildl. Mgmt.*, 4(1):63–76.

DeWitt, J. B.
1955 Effects of chlorinated hydrocarbons upon quail and pheasants. *J. Agr. Food Chem.*, 3(8):672–676.

DeWitt, J. B., and J. L. George
1960 Bureau of Sport Fisheries and Wildlife pesticide-wildlife review, 1959. *U.S.*

Dept. Interior, Fish and Wildl. Serv., Bur. Sport Fish. and Wildl., Circ. 84. 36 pp.

DeWitt, J. B., C. M. Menzie, V. A. Adomaitis, and W. L. Reichel
1960 Pesticide residues in animal tissues. *Trans. N. Am. Wildl. Conf.*, 25:277–285.

Dicke, R. J.
1960 Wisconsin's need and current use of insecticides. Dept. Entomology, Univ. Wis. 17 pp. (mimeo.)

Erickson, A. B.
1947 Effects of DDT mosquito larviciding wildlife. II. Effects of routine airplane larviciding on bird and mammal populations. *Publ. Health Repts. (U.S.)*, 62(35):1254–1262.

Forbush, E. H.
1929 The birds of Massachusetts and other New England states. Vol. 3. Mass. State Bd. Agr., Boston. 466 pp.

Genelly, R. E., and R. L. Rudd
1956 Effects of DDT, toxaphene and dieldrin on Pheasant reproduction. *Auk*, 73(4):529–539.

George, J. L.
1957 The pesticide problem / A brief review of present knowledge and suggestions for action. The Conservation Fdn., New York. 67 pp.
1959 Effects on fish and wildlife of chemical treatments of large areas. *J. Forestry*, 57(4):250–254.

Ginsburg, J. M.
1956 A survey of insecticides used in country-wide mosquito control in 1955. *Mosquito News*, 16(2):137–138.

Glasgow, L. L.
1958 Studies on the effect of the imported fire ant control program on wildlife in Louisiana. *Proc. Twelfth Annl. Conf. Southeastern Assn. Game and Fish Comm.*, pp. 250–255.

Grieb, A. F.
1957 Importance of organic phosphorus insecticides in mosquito control in California. *Mosquito News*, 17(3):166–172.

Griscom, L.
1941 The recovery of birds from disaster. *Audubon Mag.*, 43(2):191–196.

Hartenstein, R. C.
1960 The effects of DDT and malathion upon forest soil microarthropods. *J. Econ. Entomol.*, 53(3):357–362.

Hawley, I. M.
1952 Milky diseases of beetles. Pp. 394–401 *in* Insects / The yearbook of agriculture. U.S. Govt. Printing Off., Wash., D.C. 780 pp. + 72 pl.

Hensley, M. M., and J. B. Cope
1951 Further data on removal and repopulation of the breeding birds in a spruce-fir forest community. *Auk*, 68(4):483–493.

Herald, E. S.
1949 Effects of DDT-oil solutions upon amphibians and reptiles. *Herpatologica*, 5(6):117–120.

Hickey, J. J., and L. B. Hunt
1960*a* Songbird mortality following annual programs to control Dutch elm disease. *Atlantic Nat.*, 15(2):87–92.

1960*b* Initial songbird mortality following a Dutch elm disease control program. *J. Wildl. Mgmt.*, 24(3):259–265.

Hoffmann, C. H., and A. T. Drooz
1953 Effects of a C-47 application of DDT on fish-food organisms in the Pennsylvania watersheds. *Am. Midl. Nat.*, 50(1):172–188.

Hoffmann, C. H., and E. P. Merkel
1948 Fluctuations in insect populations associated with aerial applications of DDT to forests. *J. Econ. Entomol.*, 41(3):464–473.

Hoffmann, C. H., K. H. Townes, H. H. Swift, and R. I. Sailer
1949 Field studies on the effects of airplane applications of DDT on forest invertebrates. *Ecol. Monographs*, 19(1):1–46.

Hotchkiss, N., and R. H. Pough
1946 Effect on forest birds of DDT used for gypsy moth control in Pennsylvania. *J. Wildl. Mgmt.*, 10(3):202–207.

Hunt, L. B.
1960 Songbird breeding populations in DDT-sprayed Dutch elm disease communities. *J. Wildl. Mgmt.*, 24(2):139–146.

Kendeigh, S. C.
1947 Bird population studies in the coniferous forest biome during a spruce budworm outbreak. *Ontario Dept. Lands and Forests, Div. Research, Biol. Bull.* 1. 100 pp.

Kozlik, F. M.
1946 The effects of DDT on birds. *Passenger Pigeon*, 8(4):99–103.

Lay, D. W.
1958 Fire ant eradication and wildlife. *Proc. Twelfth Annl. Conf. Southeastern Assn. Game and Fish Comm.*, pp. 248–250.

Leedy, D. L.
1959 Pesticide-wildlife problems and research needs. *Trans. N. Am. Wildl. Conf.*, 24:150–164.

Lichtenstein, E. P.
1957 DDT accumulation in mid-western orchard and crop soils treated since 1945. *J. Econ. Entomol.*, 50(5):545–547.
1958 Movement of insecticides in soils under leaching and nonleaching conditions. *J. Econ. Entomol.*, 51(3):380–383.

Lichtenstein, E. P., and K. R. Schulz
1959 Persistence of some chlorinated hydrocarbon insecticides as influenced by soil types, rate of application and temperatures. *J. Econ. Entomol.*, 52(1):124–131.

Lopp, O. V.
1958 Mosquito control highlights in Illinois. *Mosquito News*, 18(2):109–110.

Luckmann, W. H.
1960 Increase of European corn borers following soil application of large amounts of dieldrin. *J. Econ. Entomol.*, 53(4):582–584.

Martin, H.
1940 The scientific principles of plant protection / with special reference to chemical control. Edw. Arnold and Co., London. 385 pp.

Matthysse, J. G.
1958 An evaluation of mist blowing and sanitation in Dutch elm disease control programs. *N.Y. State Coll. Agr.—Cornell Misc. Bull.* 30. 16 pp.

Mehner, J. F., and G. F. Wallace
1959 Robin populations and insecticides. *Atlantic Nat.*, 14(1):4–9.

Miller, W. E., and D. L. Haynes
1958 Control of the European pine shoot moth with concentrated sprays. *Lake States For. Expt. Sta., Tech. Notes,* No. 543. 2 pp.
Mills, H. B.
1955 Annual report of the State Natural History Survey Division 1954–55. Ill. Dept. Registration and Education. 24 pp.
1956 Annual report of the State Natural History Survey Division 1955–56. Ill. Dept. Registration and Education. 24 pp.
1959 Pest control in the modern setting. *Trans. N. Am. Wildl. Conf.,* 24:113–118.
Mitchell, R. T., H. P. Blagbrough, and R. C. Van Etten
1953 The effects of DDT upon the survival and growth of nestling songbirds. *J. Wildl. Mgmt.,* 17(1):45–54.
Neely, D., J. C. Carter, and R. J. Campana
1960 The status of Dutch elm disease in Illinois. *Plant Disease Reporter,* 44(3): 163–166.
Negerbon, W. O.
1959 Handbook of toxicology / Vol. 3: Insecticides. W. B. Saunders and Co., Philadelphia. 854 pp.
Norris, D. M.
1961 Insecticides for Dutch elm disease. *Amer. City,* May 1961, unpaged reprint. 2 pp.
Pickett, A. D.
1959 Utilization of native parasites and predators. *J. Econ. Entomol.,* 52(6):1103–1105.
Popham, W. L.
1960 Statement of W. L. Popham . . . . *In* Coordination of pesticide programs / Hearings before the Subcommittee on Fisheries and Wildlife Conservation of the Committee on Merchant Marine and Fisheries House of Representatives . . . on H.R. 11502 . . . 3 and 11 May 1960. U.S. Govt. Printing Off., Wash., D.C. 104 pp.
Post, G.
1952 The effects of aldrin on birds. *J. Wildl. Mgmt.,* 16(4):492–497.
Preble, M. L.
1960 Interdepartmental committee on forest spraying operations. *Canadian Dept. Agr., For. Biol. Div. Bi-monthly Prog. Rept.,* 16(1):1.
Quarterman, K. D.
1957 The use of insecticides against adult mosquitoes. *Mosquito News,* 17(4): 254–257.
Robbins, C. S., and R. E. Stewart
1949 Effects of DDT on bird population of scrub forest. *J. Wildl. Mgmt.,* 13(1): 11–16.
Rosene, W., Jr.
1958 Whistling-cock counts of Bobwhite Quail on areas treated with insecticide and on untreated areas, Decatur County, Georgia. *Proc. Twelfth Annl. Conf. Southeastern Assn. Game and Fish Comm.,* pp. 240–244.
Ross, H. H., and W. Tietz, Jr.
1949 Effect of DDT applications for mosquitoes on biota of Cook County areas. Ill. State Nat. Hist. Surv. Div. 18 pp. (mimeo.) [Original not seen; quoted from P. F. Springer, *in litt.*]

Rudd, R. L., and R. E. Genelly
1955 Chemicals and wildlife—an analysis of research needs. *Trans. N. Am. Wildl. Conf.*, 20:189–198.
1956 Pesticides: their use and toxicity in relation to wildlife. *Calif. Dept. Fish and Game, Game Bull.* 7. 209 pp.
Scott, T. G., Y. L. Willis, and J. A. Ellis
1959 Some effects of a field application of dieldrin on wildlife. *J. Wildl. Mgmt.*, 23(4):409–427.
Scudder, H. I., and C. M. Tarzwell
1950 Effects of DDT mosquito larviciding on wildlife. IV. The effects on terrestrial insect populations of routine DDT larviciding by airplane. *Publ. Health Repts. (U.S.)*, 65(3):71–87.
Shepard, H. H.
1956 The pesticide situation for 1955–56. Commodity Stabilization Serv., U.S. Dept. Agr. 17 pp.
Shepard, H. H., J. N. Mahan, and C. A. Graham
1959 The pesticide situation for 1958–59. Commodity Stabilization Serv., U.S. Dept. Agr. 24 pp.
1960 The pesticide situation for 1959–60. Commodity Stabilization Serv., U.S. Dept. Agr. 21 pp.
Simmonds, F. J.
1959 Biological control—past, present and future. *J. Econ. Entomol.*, 52(6):1099–1102.
Smith, H. S.
1946 Biological control program in relation to California agriculture. *Calif. Citrograph*, Sept. 1946, pp. 2–8. [Original not seen; *quoted in* Ecology and chemical pesticides. The Conservation Fdn., New York. 35 pp. (mimeo.)]
Springer, P. F., and J. R. Webster
1949 Effects of DDT on saltmarsh wildlife 1949. *U.S. Fish and Wildl. Serv., Spec. Sci. Rept.: Wildlife* No. 10. 24 pp.
1951 Biological effects of DDT applications on tidal salt marshes. *Trans. N. Am. Wildl. Conf.*, 16:383–397.
Steinhaus, E. A.
1960 [Discussion of biological methods of insect control.] P. 9 *in* Ecology and chemical pesticides. The Conservation Fdn., New York. 35 pp. (mimeo.)
Stewart, R. E., and J. W. Aldrich
1951 Removal and repopulation of breeding birds in a spruce-fir forest community. *Auk*, 68(4):471–482.
Stickel, L. F.
1946. Field studies of a *Peromyscus* population in an area treated with DDT. *J. Wildl. Mgmt.*, 10(3):216–218.
1951 Wood mouse and box turtle populations in an area treated annually with DDT for five years. *J. Wildl. Mgmt.*, 15(2):161–164.
Surber, E. W.
1948 Chemical control agents and their effects on fish. *Progr. Fish Culturist*, 10(3):125–131.
Tarzwell, C. M.
1947 Effects of DDT mosquito larviciding on wildlife. I. The effects on surface organisms of the routine hand application of DDT larvicides for mosquito control. *Publ. Health Repts. (U.S.)*, 62(15):525–554.

1950 Effects of DDT mosquito larviciding on wildlife. V. Effects on fishes of the routine manual and airplane application of DDT and other mosquito larvicides. *Publ. Health Repts. (U.S.)*, 65(8):231–255.

TURNER, N.

1959 Pesticides and wildlife. Conn. Agr. Expt. Stn., New Haven. 3 pp. (processed). [Original not seen.]

WALLACE, G. J.

1959 Insecticides and birds. *Audubon Mag.*, 61(1):10–12, 35.

1960*a* Another year of Robin losses on a university campus. *Audubon Mag.*, 62(2): 66–69.

1960*b* Dutch elm disease and the Robin dilemma. Unpubl. *ms.* read at 78th annual meeting, Am. Ornith. Union, Ann Arbor, 24 Aug. 1960.

WALLACE, G. J., W. P. NICKELL, AND R. F. BERNARD

1961 Bird mortality in the Dutch elm disease program in Michigan. *Cranbrook Inst. Sci., Bull.* 41. 44 pp.

WEBB, F. E.

1959 Aerial chemical control of forest insects with reference to the Canadian situation. *Canadian Fish Culturist*, 24(1):3–16.

1960 Aerial forest spraying against spruce budworm.—A problem of mutual interest in Canada and the United States. *J. Econ. Entomol.*, 53(4):631–633.

WEST, T. F., AND G. A. CAMPBELL

1952 DDT and newer persistent insecticides. Chemical Publ. Co., New York. 632 pp.

WHITTEN, R. R.

1958 The Dutch elm disease and its control. *U.S. Dept. Agr., Agr. Inf. Bull.* 193. 12 pp.

WORRELL, A. C.

1960 Pests, pesticides, and people. *Am. Forests*, 66(7):39–81.

WRIGHT, B. S.

1960 Woodcock reproduction in DDT-sprayed areas of New Brunswick. *J. Wildl. Mgmt.*, 24(4):419–420.

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